

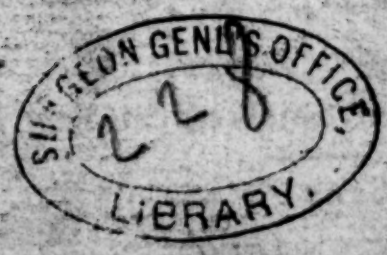
1770

AN

ENQUIRY

INTO THE

General Effects of HEAT.



THE
UNION

OF
AMERICA

1864
General Rights of Man

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AN
ENQUIRY

INTO THE
General Effects of HEAT

WITH
Observations on the Theories of
MIXTURE.

In TWO PARTS:

Illustrated with a Variety of Experiments, tend-
ing to explain and deduce from Principles,
some of the most common Appearances in
Nature.

WITH
An APPENDIX

On the Form and Use of the principal Vessels
containing the Subjects on which the Effects of
Heat and Mixture are to be produced.

LONDON,

Printed for J. NOURSE, Bookseller to his MAJESTY,
opposite Catherine Street, in the Strand.

MDCCCLXX.

ENQUIRY

INTO THE

General Effects of Heat

WITH

Observations on the Theories of
MIXTURE

IN TWO PARTS:

Part I. containing a History of Experiments, and
an Inquiry into the Nature and Properties of
the Heat of the Sun, and the Effects of
the Heat of the Earth.

WITH

AN APPENDIX

On the Force and Nature of the Magnetic
Force, and the Effects of the Earth's
Heat and Magnetism on the Production of
Electricity.

LONDON

Printed by J. G. Smith, Stationer to His Majesty,
opposite St. James's Palace, in the Strand.

1784

P R E F A C E.

THE following Enquiry is offered to the Public, rather as *Heads* of an *Essay on Heat*, than as a compleat discussion of that curious subject.—An accurate knowledge of universal Chemistry can only be obtained by an attentive observation of the *Effects* of *Heat* and *Mixture*, the two grand objects of the science. The order in which those effects ought to be traced, is a matter of considerable importance.—In the following tract, they are arranged in such manner as to form relations
betwixt

betwixt subjects, which otherwise might appear independant. — It is in this way, that several phænomena which arrange under the head of EXPANSION, become useful in explaining other phænomena referred to the article of FLUIDITY. — In like manner, FLUIDITY seems naturally to precede that general effect which is denominated VAPOUR, as several appearances in the latter are explicable on the principles of the former.

The different theories that have been imagined for explaining several interesting facts which fall within the province of his enquiry, the author

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thor has mentioned with respect, and, where they are faulty, refuted them with candour.—In place of those thus rejected he does not presume to offer any hypothesis of his own; even that of latent heat, for which he must acknowledge himself strongly prepossessed, is not his property; being the invention of the ingenious Dr. Black, professor of Chemistry at Edinburgh—a man whose modesty is even superior to his merit!

The second part is meant as an illustration of Sir Isaac Newton's theory of attraction, applied to chemical mixtures; and the appendix

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dix contains a concise account of several vessels employed in conducting chemical operations, which may, perhaps, spare the reader the trouble and expence of having recourse to more bulky volumes.

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AN

A N
E N Q U I R Y
I N T O T H E

General Effects of Heat, &c.

MANY vain and fruitless theories have been invented for assigning the cause of heat. Lord Verulam, in his Treatise *De formâ Calidi*, ascribes it to the motion or agitation of the parts of the body in which the heat is excited, or resides. Thus, heat is procured by percussion, by friction, and by collision; in all which cases, the phenomena were explained upon mechanical principles. Mr. Boyle, Dr. Boerhaave, and other eminent philosophers have improved upon this opinion of Lord Verulam.

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OTHERS

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OTHERS have ascribed to heat a cause, which, though it explains many more of its effects, is still to be reckoned fanciful and uncertain. They have supposed, that this quality or attribute of matter, is produced by an agitation, not of the parts of the body itself, but of a subtile elastic fluid that surrounds all bodies, and is known among philosophers by the name of Sir Isaac Newton's æther, a substance which that great man considered as the cause of electricity, magnetism, and a variety of other appearances.

BUT, leaving theories which pretend to investigate a cause as yet unknown, let us take a view of the more general effects of heat, beginning with EXPANSION, the simplest and most obvious.

SECTION

OF HEAT.

3

SECTION I.

EXPANSION.

ALL bodies expand or dilate themselves by heat, and contract by cold. A piece of iron heated, expands both in length and thickness : an uncompressible, unelastic fluid, as spirit of wine, suffers a similar expansion ; and the elastic fluid of air is dilated in like manner, as appears from the following simple experiment.

HOLD a half-blown bladder before a moderate fire, the inclosed air gradually expands, by reason of the constant accessions of heat, and, at length, blows out the bladder to its utmost extent. Thus, not only dense and solid bodies, but likewise fluids, whether elastic or non-elastic, dilate themselves when heated ; we may, therefore, safely pronounce expansion to be an universal effect of heat.

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ATTEMPTS have been made to estimate the proportionable expansion of different bodies in the same or different degrees of heat: but the calculations on this subject are uncertain and inaccurate. In general, dense bodies expand least. Iron, intensely heated, does not expand so much as the spirit of wine in a very moderate degree of heat. Air, an elastic fluid, expands most, and with least heat.

— COOPERS avail themselves of this expansive quality of heat, by making the iron hoops for their barrels red hot, and clapping them on quickly, whilst they are expanded: when they cool, they naturally contract, and recover their former dimensions, which keeps them firmer and closer than could possibly be effected without this precaution.

WATER, in its transition from cold to hot, undergoes an expansion in its bulk, and contracts proportionably in its return to cold: but in its transition from fluid to solid, or from water to ice, a very surprising

ing phænomenon occurs. The water, contrary to the above observations, expands and swells up, with great force, to a considerable height. Sir Isaac Newton relates an experiment which puts this matter beyond dispute. He took a large cylinder, filled it with water, and exposed it to an intense degree of cold. The water froze, and, in freezing, drove up, by its expansive force, several pounds weight which had been purposely placed upon the cylinder, to serve as a resistance. A noted experiment of the Florentine academy is, if possible, still more decisive. A metal hollow ball, one inch diameter, was filled with water, and put into a mixture of salt and ice: the water swelled to such a degree, as to burst the sides of the ball in which it was contained. A force adequate to such an effect, was computed to be 27,000 pounds weight and upwards. It is not easy to account for this curious appearance. The particles of air, say some, which, in the fluid state of the water were fixed and unelastic, recovered their elasticity or spring by the intensity of the cold,

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and thus occasioned the phænomenon in question. It is not, however, improbable, that another cause, of which, perhaps, we are ignorant, contributes equally with the elastic spring of the air, to produce this remarkable effect.

THIS curious appearance in water serves to explain the utility of frosts to the soil, when they are not succeeded by excessive rains, the reason why pavements often break after intense frosts, and why, in like severities of the weather, pieces of old houses crumble down, into which water is apt to insinuate itself through every nook and cranny. Pieces of rock even have been rent from the same cause.

To determine and measure the different degrees of heat, thermometers were constructed. Their invention is ascribed to Sanctorius, to whom physic stands indebted for the discovery of insensible perspiration. The construction of this instrument, and the principles upon which it depends, are too well known to need any explanation.

We

We may, however, observe, that since its first invention, it has undergone several alterations, in point of form. Mr. Boyle's thermometer was open at top.

BEFORE Boyle, the thermometer was applied for weighing or measuring the degrees of heat in air only. That great naturalist first employed it for ascertaining those degrees in other fluids, and the human body.

To calculate the different gradations upon the scale, especially where the stem and bulb of the glasses were of different diameters, was long an unsurmountable difficulty, in spite of the labours of Boyle, Halley, and the French philosophers, to ascertain this matter with certainty. It has, at length, been found the most proper method to insert the thermometer in snow when melting, and to let it continue till the snow is entirely melted. The liquor will fall to a certain degree, which may be considered as the snow water degree of expansion. Then inserting the same thermo-

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meter into boiling water, mark the place in the stem to which the liquor is now risen, and at which it will remain stationary while the water continues boiling. This point may be considered as the boiling water degree of expansion. We have now got two extreme points, the snow-water and the boiling-water degrees of expansion: the interval betwixt these two points may be divided in whatever proportion you please.

THIS method will answer with all thermometers of whatever diameter the bulb and stem are; for, upon inserting a smaller thermometer into snow-water and boiling-water, as above, the distance of the two stationary points marked on the scale will be proportionable to the same points in the first thermometer, although not equal in extent or expansion.

IT is a curious enquiry, whether the measure of the degrees of expansion be really an arithmetical scale of the degrees of heat. We are certain, that the liquor rising or falling in the thermometer is the
effect

effect of heat ; but is it likewise an exact measure of heat ? Several learned men have doubted of this fact ; and indeed, till of late, the question has not been accurately examined. Dr. Boerhaave was of opinion, that expansion, though the effect was not the measure of heat ; and this conclusion he drew from an experiment, in which, having inserted several thermometers of the same dimensions into boiling-water, the liquor rose with much greater velocity in some of the thermometers than in others, and was even stationary at different points.

Dr. Taylor, however, in a paper in the Philosophical Transactions, narrates a very simple experiment performed by himself, which seems to leave no room for doubt on this question. He took three vessels, one full of boiling-water, another of cold, and having ascertained their different degrees of heat on the scale of the thermometer, by plunging it in each of them, he put equal quantities of boiling and cold water in the third vessel, and immersing the thermometer into this mixture, the liquor rose to
the

8 GENERAL EFFECTS

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the middle point, between the two, ascertained as above, which confirmed him in the opinion, that the degree of expansion is an exact measure of the degree of heat : for, it is evident, that if I put equal quantities of warm and cold water into a vessel, the warm water loses one half its degree of heat. Thus, for instance, if the excess of the warm water above the cold be estimated at 20 degrees, the mixture of equal quantities will reduce that excess to 10 degrees. This is exactly what happened in Dr. Taylor's experiment. The mixture of boiling and cold water made the liquor stationary at the middle point between two extremes previously ascertained ; so that the thermometer may be justly allowed to be an exact measure of the degrees of heat.

IN making Dr. Taylor's experiment, however, a few cautions are to be observed.

1. As the cold water, when poured upon the hot, must necessarily take away from the heat that was in the vessel, and transfer it to the mixture, giving, by this means, an increment of heat to the water ; and again,

as

as the warm water, if poured into the vessel containing the cold water gives some of its heat to the vessel, which heat is lost by the mixture: it is evident, that with one trial in either way, the liquor will not exactly point at the middle distance between the extreme points of the warm and cold water; I say, with one trial: for, if you first pour the cold water upon the warm, marking the stationary point; and then the warm water upon the cold, marking in like manner the point at which the liquor stops: the mean or middle betwixt these two will give the true place or station of the liquor.

2. IT is absolutely necessary that the thermometer be perfectly cylindrical, that is, have the stem equally wide in all places. From the manner in which they are blown, it is difficult to find glasses that answer to this description. You may, however, be easily satisfied with respect to this circumstance, by observing the following simple method. Put a little mercury into one end of the stem, so as to occupy some inches,

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inches, and measure the extent or length of the column with a piece of paper : then pushing down the mercury to another part of the stem, measure it with the same piece of paper ; and if the glass is an exact cylinder, or of an equal bore, the length of the column of mercury will be equal in both places. For it is evident, that if the last station of the mercury, or that part of the stem which it last occupied, be wider, the column of mercury will be shorter ; if narrower, the column will be longer. In this manner you may always determine to a very great degree of exactness, whether the stem is totally cylindrical,

3. THE water used in this experiment should not be boiling, as it is then observed to be subject to irregular expansions.

SMALL thermometers are to be preferred to large ones, on several accounts ; more especially as they transmit the heat with greater rapidity ; for one great imperfection of this instrument is its slowness in transmitting the heat, and bringing the
liquor

liquor inclosed in it to the temperature of the particular body in question. In removing a thermometer from a warm room into a cold one, the liquor fluctuates for a considerable time before it has attained and pointed out the temperature of the room in which it is now placed. The heat is communicated, and, as it were, spent, alternately, till an equilibrium is obtained, and then the liquor will be stationary.

BUT farther, the thermometer is also imperfect, as admitting no great latitude in its range: there being many violent degrees of heat which it is by no means adapted to reach.

IT may be proper here to observe, that in measuring the higher degrees of heat, mercury should always be employed, as it can admit of a very great degree of heat without boiling and sending forth vapour, which spirit of wine is apt to do in like circumstances. In estimating the lower degrees of heat, where great depressions of the thermometer ensue, spirit of wine is
very

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very proper, as it requires the intensest cold to freeze it. The French philosophers, who went as far north as the polar circle, declare that the spirit of wine in their thermometers froze ; but they, at the same time declare, that it was very weak spirit.

OIL, from its tough, viscid nature, is always improper for this instrument.

To supply the defects of the thermometer, which is so very circumscribed in its range, Sir Isaac Newton observed the following curious method. Having taken a lump of red-hot iron, he applied it to a thermometer, when it was sufficiently cooled for that instrument to admit of such an application. He observed the points at which the liquor stood as the iron cooled, and the times in which these changes were effected. He then measured backwards ; and, having previously marked the time in which the iron lay on the ground before it was applied to the thermometer, he, from a comparison of that given time, and the spaces

spaces gone through by the liquor in their respective times, discovered the intensity of the iron when it was taken out of the fire.

ANOTHER imperfection of thermometers is, that we cannot by them determine whether one body has double, triple, or half the heat of another body. People are apt to be misled in this particular by the numerals; but as the lowest degree of heat is not known, we cannot absolutely or accurately determine upon the heat of bodies being double, or triple, of one another. When Farenheit constructed his thermometer, he marked the freezing point 32. The lowest degree of heat which he then knew being a mixture of sal ammoniac and snow water, he begun his scale from it, and marked it O, being 32 degrees below frost. Repeated trials have since brought the liquor in the thermometer several degrees below the point, from whence Farenheit began his scale. Boerhaave relates with wonder and admiration a discovery of the same Farenheit, who,

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who, with a mixture of snow water and strong aqua-fortis, or spirit of nitre, brought the liquor 40 degrees below 0 on his own scale, that is, 72 degrees below the freezing point; and yet, with whatever wonder the doctor is disposed to view this artificial cold produced by Farenheit, he well knew that such a degree of cold had been observed in nature by the French philosophers, who wintered under the polar circle. In Siberia, a very cold country, and at a great distance from the sea, the mercury sunk still more. At Keveniskoi-Ostrog, on the river Lena in Siberia, the mercury in Farenheit's thermometer fell, in 1739 to 155 degrees below 0; and yet, says professor Ammon, who relates this remarkable depression in a letter to Sir Hans Sloan, animals of all kinds have survived this cold: and although, continues he, the countries through which the great river Lena passes, are exposed to such an extreme cold, there are, notwithstanding, the finest, the most rare, and most curious plants to be found in them of any in all Siberia. The experiments made by Dr. Brown at Petersburg,

Petersburgh, mention depressions of the thermometer that are almost incredible. The mercury froze, in some of the trials, and, upon breaking the thermometers, was taken out in a solid state, part of it serving as a wire for suspending the rest: nay, some experiments relate, that it was beat out to the size of a crown-piece before it recovered its original form. 140 degrees below 0 on Farenheit's thermometer seem to be the greatest depression for which there is any evidence, though 200 and even 300 are insisted upon. The truth is, as the mercury, in some of the experiments, confessedly froze, it must have passed through the range of the tube irregularly, and by starts, falling often 100 degrees at a time; a circumstance which could not fail to involve the whole series of experiments in uncertainty and error.

WE have seen the principles on which Farenheit constructed his thermometer, and the degree of heat from whence he begun his scale. Succeeding improvers of this useful instrument, not observing Fa-
 C renheit's

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renheit's method, made some other degree of heat their fixed point, and reckoned both above and below it. The heat of the animal body, which Farenheit placed 96 degrees above 0, and 64 above frost, served as the highest point to some. The degree of heat at which water begins to boil, is placed 180 degrees above frost, and 212 above 0, and is the highest degree on Farenheit's scale. From this degree M. de l'Isle begins his scale, calling it 0, and reckoning downwards in a direction retrograde to that observed by Farenheit.

To reduce all the different computations on this subject to a general standard, Dr. Martin has composed tables, in which he brings all the different degrees used by succeeding philosophers to the standard of Farenheit's thermometer.

IN speaking of heat, I would always consider it as something positive. Cold I would regard as its negation or privation, the absence of heat. But though it may
be

be allowed, that these two terms heat and cold are so related, that the one is positive and the other negative : yet, is there not as good reason to call cold the positive quality, and heat the absence of cold ? Are we not sensible of two very different sensations, both disagreeable, when we touch a piece of ice, and a bar of red hot iron ? To obviate this objection, let it be considered, that no cause can be assigned for cold, unless the absence of heat only. The sun is the cause of heat, and a very powerful active cause it is : when his influence prevails, I feel myself warm : when he describes a longer range in the heavens, the heat increases : when he retires behind a cloud, the heat abates, and I become cold. What cause can be named equally capable of producing cold ? Is it not produced by the absence of the sun, and by the sharp and violent winds that blow from those quarters of the earth, which the sun visits but seldom, and with his less influencing rays ? Till a cause as adequate for producing cold is discovered as the sun is for producing the animating effects of heat, we must rest

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satisfied with characterizing heat positive, and cold negative. To say the truth, we know but little of heat: we cannot tell when cold ends, nor where heat begins. The same water in a vessel, shall to one hand appear warm, and to the other cold, if your hands are unequally heated. The greatest degrees of cold, therefore, that we know, are to be considered as lower degrees of heat.

WE have thus seen the great utility of thermometers in measuring degrees and differences of heat; for, proportions of heat they are not adapted to measure, as we know neither the lowest nor the highest possible degree of heat.

WHEN heat has entered into a body, it communicates or transmits it to all the bodies in its neighbourhood; and that till an equilibrium is obtained betwixt the heated body and those around it. There is, as it were, a continual fluctuation from the one body to the other, till they have all become of an equal temperature. This
is

is obvious from common and rude observation. A number of different substances, as wood, feathers, iron, &c. of different temperatures, being placed in a room where the sun's beams are not permitted to enter, the heat in the warmest body will begin to diffuse itself over the other substances that are heated to a less degree, and will so continue to fluctuate from one to another, till they have all arrived at the same degree of temperature, that of the room, as will be evident by placing a thermometer at each of the substances in question. The liquor will fall exactly at the same point in all.

IN considering heat, we are to attend, not to the degree or intensity only, but likewise to the quantity of heat. The same substances, heated to a like degree of intensity, will, if different in quantity, have different quantities of heat. Thus, two pints of water contain double the quantity of heat which one pint of the same fluid contains, heated to the same degree. The ratio then of the quantities of heat in the same bodies is directly as the quantity of

C 3 matter.

matter. We might even be naturally enough led to suppose, that the same ratio obtained in estimating the quantities of heat in different bodies ; for instance, that mercury, whose specific gravity is to water as 14 to 1, should contain, in equal bulks, 14 times as much heat as water, heated to an equal degree. Dr. Boerhaave and Desaguliers, from the equivocal success of some experiments, seem to have been of this opinion. By more recent, however, and better attested experiments, mercury is found to contain less heat than an equal bulk of water heated to the same degree, and to arrive at the acquired temperature in a less time. An equal bulk of water being heated and poured into or mixed with cold mercury, is found to communicate a greater quantity of heat, than when the mercury heated to the same degree is poured into an equal bulk or measure of cold water. Thus, if the mercury is heated to 50 degrees, it communicates only 20 degrees of heat to the mixture ; whereas water is heated to the same degree, is found to communicate 30 degrees of heat to the mercury.

mercury. In the same way we may calculate, by experiments, the quantity of heat in any body, from its communication with others, and estimate to a degree of exactness, any violent heat which far exceeds the range of the thermometer : thus, of the furnace of a glass-house ; by putting a stone into the oven, making it as hot as possible, then plunging it into cold water, till the temperature or equilibrium is restored, and applying a thermometer, the degree of heat communicated to the water will enable us by some known ratio to estimate the heat of the stone when taken out of the furnace.

THE ratio of the times in which different bodies heat or cool, was long believed to be as the density of those bodies ; but this theory is now found by experiments to be manifestly false. These experiments prove, that mercury, which is 14 times heavier than an equal bulk of water, passes from heat to cold, and from cold again to heat with much greater celerity than water. The times then seem to be propor-

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tioned, not to the density of the bodies, but to the quantity of heat required to bring different bodies to the same temperature. Mercury requires less heat than water, and therefore arrives at its temperature in a less time.

HEAT transmits itself in greatest quantities to those bodies which are most in contact with the heated body. A heated sphere communicates very little heat to another sphere : a heated cube communicates a larger quantity of heat to another cube. The sides of the last touch ; the former meet but in a physical point.

HEAT is communicated with greater celerity, and in larger quantities, in proportion to the broadness of the surface. Bodies of unequal bulks, but of the same figure, have the heat transmitted and diffused unequally ; yet, the lesser body will transmit it with greater velocity than the other ; for, though in the lesser body, the surface is smaller, a less quantity of heat is contained within it, which more than
compensates

compensates for the broadness of the surface in the greater body. For this reason, as large vessels as possible are most convenient for the purposes of distillation, as a great waste of heat, and thereby of fuel is prevented.

SOFT spungy solid substances communicate heat very slowly; those that are more compact very quickly. A piece of iron heated to a great degree, will affect your hand holding the end of it: a piece of wood, in the same circumstances, occasions no uneasy sensation. In the same way, wool, feathers, &c. which are generally thought to increase heat, do, in reality, nothing else than retain it; and, as these soft bodies are equally slow in transmitting heat and cold, we find them proper for preserving the natural heat of our bodies, and accordingly, use them for cloaths, beds, and other conveniences. Hence the great advantage of furs in the cold northern climates. I said, that these very substances, are equally slow in transmitting cold. Accordingly, straw and other
soft

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soft spongy bodies are employed in the ice-houses to prevent the entrance of heat.

WATER, though rare, transmits the heat with great celerity ; and, as all its parts are equally heated, is very properly used as a medium for heating other bodies. That all its parts are equally heated, is evident from the process of boiling water. The heat, communicated from below, first affects the lower part of the water, rarifies it, and makes room for the colder water from above, to be rarified by the heat in like manner, and forced upwards : by this means, all the different particles of the water, being heated, as it were, by rotation, the whole mass soon becomes of an equal temperature of heat. Such a temperature cannot be so easily obtained in solid bodies, as the metals, glass, and other substances, which being exposed directly to a great heat, are apt to be unequally heated, and frequently, from that cause, to break or burst. For this reason, fluids, as water and air, have been employed as mediums in transmitting a violent heat

heat to such bodies as cannot, without danger, be exposed to its immediate action. These mediums, are called by chemists Balnea or baths ; that of water is stiled Balneum-mariæ.

IN very cold countries, the great falls of snow preserve the ground, which would otherwise be rendered totally barren by the excessive and long continued frosts. Snow being a soft spongy substance, and transmitting heat but slowly, beds of it to a great depth prevent the chilling air from sweeping along with it the heat contained in the soil.

DEEP waters are observed to freeze with greater difficulty, and in consequence of an intenser degree of cold than those which are shallow. The appearance is common, and therefore the cause is little attended to. The water being equally heated, as was demonstrated above, gives less resistance to the cold which would act upon it, in proportion as it is shallower, or contains a less quantity of heat. Hence also,
rivers,

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rivers, especially if rapid, are seldom observed to freeze. Their motion, and the equal distribution of heat in them, require a great degree of cold to produce refrigeration, which must, in a manner, be instantaneous. The depth of the ocean renders it almost impossible to be frozen.

IN Siberia, very great depressions of the thermometer have been observed; greater, indeed, than might naturally have been expected from the latitude of the country. The reason was formerly suggested. Siberia is surrounded by a great extent of continent, and is situated at an immense distance from the sea. That large body of water has a mighty influence in giving a proper temperature to the lands in its neighbourhood. Snow is never observed to lye on the ground for any considerable time, in islands, at least, in those parts most contiguous to the sea. In Siberia, the cold winds from the north, sweeping along with them a very small portion of heat from the surface of the countries through which they have passed, must render the
cold

cold very extreme. Winds blowing from the sea, or a collection of waters, always carry along with them a great quantity of heat, which they waft into the countries for which they are destined. The air, however, does not possess the same quality as water, that of being equally heated. The lower parts of the atmosphere are manifestly warmer than the superior regions, which are so very cold, that on some of the highest mountains, as the Andes, snow is observed to lie the whole year. The intense cold of the higher parts of the atmosphere is likewise deducible from the hail showers in summer, which manifestly come from a great height, and are nothing else than rain condensed into that appearance by the superior cold of the higher air, which, in the form of clouds and vapour, they had reached.

THE lower part of the air is heated by reflection from the surface of the globe. Heat passes from the sun to the earth without affecting the medium of air, provided that

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that medium is transparent. As it is, however, frequently encumbered with vapours, a small allowance of the diminution of its force ought to be made upon that account ; yet, in general, the air is only heated in a secondary way from the earth. The heat, therefore, it is evident, must necessarily effect that part of the air which is most contiguous to the earth, in a greater or superior degree.

BUT why are the superior regions so much colder ? Why is not the heat, as in water, diffused through all the parts of air equally ? This depends upon a certain property of air, its compressibility. The air next the earth is much denser, or contracted into a smaller compass than that which is far above it, because it has a much greater weight of incumbent air to sustain, so that its density becomes always less as you remove from the surface of the earth, till, on ascending high mountains, it becomes remarkably thin and rare. Now, though the heat of the surface of the earth affecting
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the lower air that is contiguous to it, must occasion a rarefaction of that air; yet, in fact, that rarefaction goes to a very inconsiderable height: the rarefaction and thinness of the upper or higher air, occasioned by a less pressure being sustained, far exceeding that which arises from the heat of the earth acting upon the lower air, and destroying, in a great measure, its effect.

BODIES when heating and cooling, make very different impressions on those in their neighbourhood. A piece of red-hot iron suspended in air, seems to act principally upwards. During the first minute, it rarifies a certain portion of air, which makes room for another quantity to be rarefied in like manner, and so on, till an equilibrium or proper temperature is obtained: but while this tremulous undulatory motion of the air, which sometimes may be rendered visible, continues, the effects are more obvious above than below, as will be sensibly felt by a person
who

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who holds his hand first in one direction, and then in the other. This however, it is to be observed, does not succeed *in vacuo*. On the other hand, a piece of ice suspended in mid-air, seems to act with greater force below ; the air contracts below the ice, and it will feel sensibly colder there than above.

SECTION

SECTION II.

FLUIDITY.

ANOTHER universal effect of heat, is FLUIDITY : that quality by which bodies, on the application of heat, are rendered fluid. I call this an universal general quality, or effect of heat ; because it is found to obtain in most bodies which are exposed to violent degrees of heat, and where no such effect has yet been found to take place, we ought not rashly to infer, that no possible degree of heat would be adequate for that purpose ; but rather to conclude, that no heat which we have been able to apply has been intense enough to produce fluidity in the substances in question.

As bodies in a solid state are rendered fluid by the application of heat, so fluids preserve their fluidity by the heat which they contain. This is evident from most fluids putting on a solid form, or the appearance of ice, when, by any means, they are robbed of their heat.

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Some fluids, indeed, as mercury and spirit of wine, are rarely observed, even in extreme cold, to freeze or assume a cold form ; we are not hence to infer, that such substances are not kept fluid by their internal heat, or that they cannot be reduced to a state of solidity : we are only to conclude, that a greater intensity of cold is requisite to rob them of their heat, and so destroy their fluidity. Experiments on thermometers for about four years past have assured us that mercury, however much disposed to continue in a state of fluidity, has been frequently overcome by the superior cold, and put on a metallic solid form.

MR. Muschenbrook is very unwilling to believe that the freezing of water is owing to a diminution of the heat of the water in its fluid state. He attributes this effect to the influence of a certain congealing matter, which, mixing with the water, produces freezing. In support of this conjecture, he advances a number of arguments, drawn principally from observations on water freezing, from the temperature

rature pointed-out by the thermometer, compared with the real temperature of the air, and from other circumstances. Many of these observations contain facts that are curious; but the inference which he draws from them is neither accurate nor satisfactory. He tells us, that a mixture of salt and snow in one plate, and a quantity of cold water in another plate above the former being exposed in this situation to the action of the fire, the water in the uppermost began to freeze, as soon as the snow in the other, had, by the heat of the fire, begun to melt. Can it, says he, be pretended, that the heat communicated from the one plate to the other, directly from the fire, shall rob the uppermost plate of its heat, and dispose it to freeze? may we not rather, with much greater probability conclude, that the congealing matter, expelled by the heat, from the lower plate, passes into the higher, and thus produces the curious appearance in question? But this experiment, which, at first, appears a little perplexing, will come to nothing, when it is observed, that to produce the freezing of the water, it

is not necessary to put the apparatus on the fire. This circumstance seems to be so much insisted upon, in order to give a wonderful and mysterious air to the experiment. In fact, a plate of water, in such circumstances as above, will freeze, and to a much greater degree, without being applied to the fire. True, indeed, the action of the fire is so inconsiderable compared to the intensity of the cold in the undermost plate, that it will not have force sufficient to keep the water fluid.

THE same learned philosopher also pretends, that the great expansion of water in its transition from a fluid to a solid state, is an insuperable objection to the prevailing doctrine, that fluidity is occasioned by heat, and solidity by its diminution or absence. Ice, says he, expands, because of the congealing matter which mixes itself with the water, and thereby increases its bulk: but, for the same reason, should it not increase its weight likewise? the fact is otherwise. Mr. Muschenbrook does not pretend to deny it. It is not in water only that this expansion happens.

pens. A similar expansion is observed in iron, in its transition from a fluid to a solid state. Will any one pretend, that at the very time of expansion, a certain congealing matter mixes itself with the iron, to produce that effect?

BUT, without dwelling longer upon this subject, I would lay it down as a general and fixed rule, that fluids retain their fluidity by heat, and lose it, when, by any means they are deprived of that heat. At the same time, I would beg leave to repeat what was formerly urged, that all solid bodies are such from a diminution or absence of heat, and may be rendered fluid by its application. In some solids, indeed, the diminution is greater than in others. Some, to be rendered fluid, require a greater, others a less degree of heat: some have never yet been rendered fluid; but these are not, for that reason, to be pronounced incapable of fluidity: a greater degree of heat than has hitherto been applied might have possibly produced it. A collection of the sun's rays, in the focus of a lens or speculum, has been known to melt, with great facility,

stones and other substances, which the application of the strongest fire could not affect.

WHAT makes it more probable that all bodies are capable of fluidity, is, that the hardest substances, which, by themselves, resist the action of the most violent fire, will, when mixed together, yield to the force of a very moderate heat, and be rendered fluid. This is confirmed by a variety of experiments.

THE action of expansion differs from that of fluidity in this, that whereas the former varies in every variation of the degree of heat, fluidity is effected by a certain fixed degree, which, if increased, will make no farther alteration, in that respect, upon the body exposed to it. A certain degree of heat melts iron. Increase the degree you still but render the metal fused. In the same manner, the diminution of heat, necessary to produce freezing, is a fixed point. Increase the cold, you have the fluid still reduced to a solid form.

BODIES, which, having undergone a total change from a solid to a fluid state, are again reduced to a substance entirely dissimilar to their original form, are said to be vitrified: and the process is called, by a chemical term, vitrification. Vitrified substances, if melted, and allowed to cool, will always put on the same form.

I SAID that fluidity is occasioned by the presence of heat. Yet is it scarce credible that a quantity of sensible heat which affects the thermometer so little, should be productive of so extraordinary an effect. Is it not rather to be believed that bodies absorb degrees of heat, which, in certain circumstances, remains latent and unobserved? and that fluids contain a great quantity of this latent heat, which, though it does not act sensibly, that is, pass easily from one body to another, is capable of producing, or, more properly, of preserving fluidity? that the latent heat never disappears, or loses its influence in preserving fluidity, till the cold has become so far superior as to bring the fluid to the freezing point? that then it dis-

appears gradually, and but gradually, else the fluid would be converted at once into ice ; which is not the case, greater accessions of cold, and of a longer duration, being requisite to make fluids assume a solid form.

IN the same manner, the absorption of latent heat is observable in the reduction of a solid to a fluid—as of ice to water—a very great quantity of heat is absorbed before the ice begins to melt, a quantity more than sufficient to bring the temperature above the freezing point, if the heat so absorbed acted sensibly, or could be measured by a thermometer. What then becomes of this large portion of heat, which has incontestably entered the ice ? It has been absorbed by the ice, and lies concealed in it in a latent form.

IN this way are we to account for the large quantities of ice to be seen on the surface of the earth after long frosts, for some days after the thaw has commenced. After severe frosts, the weather is generally very warm : how comes it that the ice, exposed to the heat of the air is not immediately melted ? Each
piece

piece of ice being examined by the thermometer, will be found to be cooled to the freezing point; yet it cannot be denied, that every such piece must be affected by the warmth of the atmosphere, and the influence of the sun. What then becomes of this heat, which, as far as we can judge, has no sensible effect? It is evidently absorbed by the ice, and contained in it latent. In the same manner, ice, in ice-houses, notwithstanding all the precautions that are used, could not fail of melting, if all the heat it received acted sensibly; but that is not the case, great part of it being absorbed, remains latent, and, of course, has no sensible effect.

THE following experiment is decisive upon this subject. Into a vessel was put some water cooled nearly to the freezing point; into another a quantity of ice: by a thermometer the change made upon the water during the first half hour, by the temperature of the warm room, in which the vessels were suspended, was observed, and it was found to have raised the liquor 7 or 8 degrees above the freezing point: no change was observable in the ice,
save

save that a very little of it was melted; but what was so melted, was found, by the thermometer, to be equally cold with the mass of ice. The vessels hung, in this manner for 11 1-half hours, at the end of which time all the ice was melted. Now, as each vessel received from the temperature of the room in which it was placed, about 7 degrees of heat every half hour, it is evident, the vessel containing the ice, must, at the end of 11 hours and a half, have received upwards of 140 degrees of heat; that is, the quantity of heat flowing into the vessel, during that time, must have amounted to the number of degrees specified. But this heat plainly did not operate in melting the ice, for then it should have produced that effect at the end of the first half hour, when 7 or 8 degrees of heat must have entered the ice; whereas, that effect was not produced till the end of 23 half hours, when, by calculation, 140 degrees of heat, and upwards, must have successively passed through that substance. This heat then did not act sensibly: no; it was latent in the ice, and absorbed by it.

It may probably be said, that the heat communicated by the air did not enter into the ice, but was repelled by it : but this cannot be ; for, by experiment, a quantity of warm water being poured upon ice, that substance, in a manner, instantaneously melts, without repelling, in the smallest degree, the heat that is thus forced into it.

By the theory of latent heat are explained the curious phenomena of artificial colds produced by mixture, as of snow-water and salt : when these two are mixed, the sensible heat is converted into latent, therefore the mixture must be sensibly colder ; at the same time, the latent heat operates its usual effect in keeping the mixture fluid, which would otherwise have a tendency to consolidate.

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SECTION III.

V A P O U R.

A THIRD general and universal effect of heat, is that by which it disposes bodies to assume the form of a rare, subtile and elastic fluid, called vapour or steam.

THE vaporific point of bodies is different as the bodies differ; some being more disposed to evaporate or fly off in steam than others. From this difference of aptitude for disposition to produce steam or vapour, some bodies are denominated volatile, whose parts, with a small degree of heat, are inclined to fly off in this manner; others fixed, which require a greater degree of heat to produce that effect; and such bodies as resist the most violent heat, without discovering any tendency to emit vapour, are said to be perfectly or compleatly fixed.

THIS general effect of heat is observable in the most common occurrences of life. A
drop

drop of water in a tea-kettle being put upon a fire, will, in a short time, disappear, having entirely put on the form of vapour. This vapour or steam, if not allowed to have its proper range or spring, will often, upon the addition of more heat, burst the vessel in which it is thus confined: the heat acting upon it as upon a quantity of air, rarifies it, and of course makes a greater compass or range necessary.

IT is upon this effect of heat to make bodies emit steam, which is again condensed by cold, that the fire-engine for raising water immense heights depends. Upon it, likewise, is founded the curious process of distillation.

THOUGH the production of vapour is in a great measure to be attributed to heat, yet is that production not a little influenced by another cause, I mean, the pressure of the air. Experiments demonstrate, that as this fluid presses more or less upon any body, it disposes that body to heat proportionably later or sooner. A quantity of water moderately
warm

warm being put into the exhausted receiver of an air-pump, boils and sends forth steam; whence it follows, that, if the pressure of the air were taken off, bodies would heat much sooner, and, of course, arrive sooner at their vaporific point.

THE degree of heat at which water begins to boil, is always considered as the vaporific point of that fluid; because it is then first observed to send forth vapour or steam. The violent agitation which is found to accompany water and other fluids in these circumstances, has been variously accounted for. Some have imagined, that water, after receiving a certain determinate quantity of heat, is saturated with it, and will admit no more; the heat from below, continue they, is, however, still forcing its way into the fluid; and this violent exertion of force on the one hand, and the no less violent resistance on the other, co-operate in producing the agitation in question. Certain it is, water is not sensibly hotter during the whole time of boiling than when it began to boil, although great accessions of heat are every moment making their

their way into it. Yet is this theory inaccurate and unsatisfactory ; heat, in its progress through bodies being frequently retarded in its motion, never forcibly obstructed.

OTHERS have attempted to explain the agitation in boiling, from the elasticity or spring of the air. That subtile fluid, say they, which enters more or less into the composition of all bodies, remains fixed and unelastic in the water, while cold ; but, upon the application of heat, resumes its elasticity, seeks to extend its range, and meeting with resistance from the dense body of water through which it must necessarily pass, rends and tears it in a violent manner, and thus occasions that concussion which is denominated boiling. But neither is this theory probable nor adequate to explain the appearances.

THE true solution seems to be, that the heat coming from below, first affects the water in the lower parts of the vessel, and disposes it to fly off in steam. This rare and thin substance having to force its way through a dense bulky mass immediately above it,
must

must occasion a violent agitation in the water; especially, as a succession of the parts of that fluid is constantly attempting a passage through such forcible opposition.

ONE great cause of fluidity was found to be latent heat absorbed by the fluid, without acting sensibly, or being measureable as sensible heat; the same cause seems to operate in the emission of steam from water or other fluids. This is almost evident by induction from the above observations. Boiling water being examined by a thermometer is not sensibly hotter after boiling two hours than when it began to boil; though, to maintain it of that degree of temperature, a brisk fire must necessarily be kept under it. What then becomes of this great waste of heat? It is not in the water: it is not in the steam; for steam, upon examination, is rarely found hotter than boiling water; if there is any difference, it is quite inconsiderable.

Two broad bottomed vessels of like form and bulk, inclosing equal quantities of water, were put upon a large plate of heated iron, called

called a kitchen-table. In four minutes they begun to boil and send forth steam, and at the end of 20 minutes, the plate being still of the same degree of heat, the water was wholly evaporated. At the beginning of the experiment, the water was of the temperature of 54 degrees, the heat of that fluid in summer; in 4 minutes it rose 158 degrees, or to the boiling point; and, during each of the succeeding 4 minutes, it received the same quantity of heat, that is, in 20 minutes, 5 times 158, or 790 degrees. If the steam had gone off with greater velocity, we might have judged that this was a sensible effect of the increase of heat; but, as neither the heat of the water is sensibly increased by the duration of boiling, nor the steam sent off with any remarkable celerity, we may reasonably conclude, that the great quantity of heat which has indubitably entered the water, is absorbed by that fluid, and contained in it latent.

WHAT makes this conclusion highly probable, is, that the latent or absorbed heat acts sensibly upon the steam's being condensed by cold. This is particularly manifest in the

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condensation of the liquor in the process of distillation ; where, upon examining the refrigeratory, a much greater quantity of heat appears to be communicated to it, than could possibly have been transmitted by that heat which acted sensibly in the liquor before condensation.

To be satisfied about the absorption of latent heat, by fluids that have attained the vaporific point, I put a small quantity of water into a phial closely corked, and exposing it to a sand heat, soon brought the temperature several degrees above the boiling point, which I could easily effect, as the pressure made the fluid capable of receiving greater accessions of heat. The steam which arose could not have vent, so that upon taking out the cork, after an interval, in which all the water might have been converted into steam, I expected the whole would immediately disappear and be changed into vapour, which, as I imagined, would rush forcibly out of the phial. This did not happen. Upon taking off the mechanical pressure, an ebullition and agitation of the water ensued, during which, a portion
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of that fluid rushed out of the phial along with a quantity of steam. The remaining water sunk down to the boiling point, though before it had been considerably above it. What then became of this quantity of heat? Was it annihilated? It does not appear in the water, though the minute before it acted sensibly in it, by elevating the liquor in the thermometer several degrees above the boiling point. That sensible heat is converted into latent, and, though it no longer appears to act sensibly, resides in the water. The following experiments are equally decisive upon this subject.

A VERY large quantity of water being put into Papin's digester, was exposed to the action of a violent fire, which soon brought the temperature 300 degrees above the boiling point; a degree of heat, of which water is susceptible under great mechanical pressure, as in a vessel of this kind. After confining the steam for a long time in such an increase of heat, I naturally judged, that, upon admitting the air, or giving vent to the obstructed steam, the whole mass of water would instantaneously

neously evaporate. But here too, as in the former experiment, I was deceived; for, though, upon removing the pressure, a quantity of steam burst out of the vessel with such impetuosity, as to rattle several times against the ceiling of the room in which the experiment was made; yet, by far the greater part of the water remained in the vessel; and what so remained, almost immediately sunk to the boiling point, that is, 300 degrees below its temperature at the time of removing the pressure. This heat must certainly have been absorbed by the water, and, from its acting sensibly, have been converted into a latent form. Nothing else could have produced so instantaneous a change.

IN performing an experiment, with a view to estimate the vaporific point of bodies in their natural state, or without the pressure of the air, I likewise found reason to acknowledge the great absorption of heat by fluids that have attained that degree of temperature. Water, as I before observed, arrives sooner at the boiling point *in vacuo*, than when exposed to the pressure of the air. Hence I concluded,
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a great waste of fuel might be prevented, if steam or vapour could be produced with a less degree of heat than is generally required for that purpose. Taking a copper still, I put into it some substances with water, and, in order to exhaust the air, heated the water to the boiling point, both in it and the cooling-vessel or refrigeratory. When they sent forth steam, and of course excluded the air, I corked them closely up, and applying a moderate fire under the still, which had been previously allowed to cool, the water soon began to boil. The steam was about animal heat, or 96 degrees on Fahrenheit's scale, instead of 212, the boiling point. Here then was a great deal gained in that article—though, on the other hand, the liquor was very slow in condensing. But what most particularly engaged my attention, was, that, upon examining the refrigeratory, a much greater quantity of heat appeared to be there accumulated, than acted sensibly in the serpentine-pipe before the steam was condensed by the cold water, nay, greater than what would have been communicated by the same steam, though it had been of the ordinary heat of boiling water,

that is, 212 instead of 96 degrees. What are we to infer from all this, but that the sensible heat was converted into latent heat, which made its appearance, when the vapour was condensed by cold.

THOUGH the vaporific point is generally above the melting point, yet in several bodies, as camphire, and sal ammoniac, a slight degree of heat is sufficient to make the parts fly off in vapour—a degree much inferior to that which is productive of fluidity. Hence it has been doubted, though, I think, without reason, if such bodies, or, at least many of them, are capable of fluidity. That they are rarely found in a fluid form is certain, and, for the reason but now suggested, must not appear surprizing: but it is equally certain that they might attain fluidity, if the heat required to effect it, were not more than sufficient to produce a total evaporation.

UPON this effect of heat are explained several curious processes in chymistry, as evaporation, distillation, and sublimation,

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When bodies are compounded of different substances, we may always separate them by the means of vapour, provided the ingredients are of different degrees of volatility, and cohere together but slightly. A composition of clay, water and quicksilver, being exposed to heat, the water, as most volatile, will evaporate first, next the quicksilver, and the clay being highly fixed, will remain at the bottom of the vessel.

If the steam is suffered to escape, and the fixed body left at the bottom, the process is called evaporation, as in separating salt from sea-water.

DISTILLATION, and sublimation, agree in this, that the volatile parts are preserved by means of cold, which condenses the liquor; but differ in the form which the substance assumes after this condensation. In distillation, the product is a liquor, frequently a spirit. In sublimation, the product is a solid, and is called sublimate, or flowers—a greater degree of heat being required to reduce this substance to a liquid form.

ANIMAL and vegetable substances being exposed to heat, contrary to what is observed in other bodies, contract; and expand proportionally by cold. Thus a piece of wood, put into the fire, becomes shorter; and, if the heat is increased, will be entirely consumed. The salt, oil, and water, which exhale from it, shall never be able, by their composition, to form a substance like the original wood. The reason of this appearance is manifest. The wood, upon the application of fire, is contracted, because the water, which fills the interstices of that spongy substance, is exhaled, or puts on the form of vapour, leaving its room to be supplied by the wood itself, which becomes, by that means, closer and more compact. Again, as this substance is exposed to cold, it is liable to absorb quantities of water, which serve to expand it.

IT is a curious question, and deserves attention, Whether heat really acts as an universal agent in disposing bodies to evaporate, in the same manner as we have seen it universally promote fluidity. Perhaps it would
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be rash to conclude at once that all bodies are capable of being volatilized. Certain it is, there are many earths, which may, by violent heats, be rendered fluid, but have never been observed to suffer a diminution in their weight, or emit any thing like vapour. But it is equally certain that we know not what is the most violent possible degree of heat; and that, till such a degree is ascertained, it would be highly unreasonable to conclude that these earths cannot be volatilized. It was long imagined that gold and silver were perfectly fixed—and many experiments seemed to favour the opinion. Mr. Boyle put a quantity of gold in the hottest part of a glass-house, and allowed it to continue there two months, at the end of which time, he found the gold in a state of fusion, but not perceptibly diminished in weight. Experiments on a quantity of silver were equally void of success. The mass of silver had, indeed, lost a little of its weight, but it was so little, that Mr. Boyle supposed the diminution to be occasioned by some impurities in the metal, which, as he imagined, had been destroyed by the action of the fire.

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More recent observations, however, and with a more violent heat, that, viz. of the focus of a burning-glass or mirror, evidently demonstrate that gold emits steam in considerable quantities, which, when condensed, falls down in small globules of that metal. What happens to the gold we may fairly infer will happen to the most fixed bodies, comparatively speaking, provided a degree of heat sufficient to bring them to the vaporific point, is applied. So readily, indeed, are some philosophers for making its power in producing elastic vapour an universal effect of heat, that they consider every elastic vapour as owing its existence to heat.

THE air is a body which exactly resembles the steam or vapour raised from water. Like it, it is elastic—and, like it, its elasticity depends on heat. The greater heat gives the air a greater spring; if the heat is removed, the air is-compressed, and loses that spring; and, were it possible to produce such a degree of cold, it would be frozen in very extreme diminutions of its heat.

ANOTHER

ANOTHER kind of vapour, which rises more or less from all bodies, may be called spontaneous vapour, because it exhales with very little heat, and is generally imperceptible. Camphire in a phial, that is not corked, will exhale very quickly in this way: cold water spends a considerable quantity, and even ice. As this evaporation is perfectly quiet, it must evidently proceed from the surface only; and, as that surface is enlarged, must be proportionally greater. Equal quantities of water being put into two unequal vessels, the one broad and shallow, the other narrow and deep, the former will exhale much more abundantly than the latter.

UPON the theory of spontaneous evaporation are explained some of the most common appearances in nature. When a cold vessel is brought into a warm room, particularly where many people are assembled, its outside will soon be covered over with a sort of dew. The reason is obvious. The vapours arising from animal bodies, particularly those from the lungs, being carried away by the surrounding air, are there kept
buoyed

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buoyed up, till meeting with a cold body, as the vessel just now mentioned, they fall down in drops upon the sides. In the same manner we may account for the frost on the inside of windows, which is nothing else than vapour, particularly animal vapour, condensed, by the superior cold, into the form of ice. The cause of dew may be likewise traced upon the same principles. During the influence of the sun in the day-time, the earth is disposed to exhale in considerable quantities. These exhalations, during the night, which is comparatively colder, are condensed, and put on the appearance of drops of dew.

WIND, or air in motion, favours greatly the raising of these spontaneous exhalations. Stagnated air has the contrary effect. Hence the mists which are often seen at a small distance from the surface of lakes.

As the quantity of this kind of vapour is in proportion to the surface of the bodies from which it is emitted, such a large mass as the sea must necessarily exhale in great
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abundance. Accordingly, such exhalations are of themselves sufficient to explain most of the phænomena of the weather, without the aid of those raised from the earth and animal bodies. The vapours, that rise spontaneously from this immense collection of waters, are carried aloft, assume the form of clouds, which being condensed by the cold of the superior regions, fall down in rain, mist, snow, or fleet, appearances which have each its respective uses, and depend upon the degree of intensity in the condensing cold. Thus condensed, they either run below the surface of the earth, and become the origin of fountains, or dwell upon it, and become marshes and lakes.

VARIOUS hypotheses have been framed for explaining the phænomena of vapour. Philosophers were sensible that the subject demanded attention, as so many of the appearances of nature were only to be explained on the principles of spontaneous evaporation.

MR.

MR. DERHAM's theory proceeds upon a fancied analogy betwixt the exhalations in question, and the steam which is raised from boiling water. This steam, and of consequence those exhalations, he conceived to be nothing else than portions of air, which, remaining fixt and unelastic in the water while cold, have their elasticity restored on the application of heat, and, accordingly rise upwards, inclosing in each bubble, a portion or film of water, which, being lighter than the air wherein it floats, is still carried aloft, till, meeting with the superior cold of the upper regions, it is condensed, and, as that cold is more or less prevalent, falls down on the earth in the form of snow, fleet, rain, or mist. This hypothesis, however plausible, has never been adopted by any, but its author.

ANOTHER theory is that of Mr. S' Gravesend, afterwards adopted by Muschenbrook, and depends upon the comparative rarity or expansion of steam. Mr. S' Gravesend pretends, that steam sent forth from boiling water, that is, at 212 degrees on Fahrenheit's thermo-

thermometer, is 14000 times rarer than water; whence he concludes, and with reason, were the computation just or accurate, that a heat, which is only as 32 degrees, or the freezing point on Farenheit's scale, will produce as much vapour as is sufficient to explain the appearances of clouds, rain, snow, and the other phænomena. But Mr. S' Gravefend has been extravagant in his calculation; for, by accurate experiments, water, which is more rarified, in the form of steam, than any other fluid, is found, in that form, to be only 1800 times rarer than cold water.

THE latest and most ingenious theory that has appeared on this subject, is that of M. Le Roy, a Frenchman, who first communicated it in the Encyclopedie; though the same theory is said to have been known to a celebrated gentleman of our own country. In this theory, the air is supposed to act as a menstruum or solvent; the substances evaporated are said to be dissolved in that menstruum. In the process of solution, one of the bodies is active, the other passive. The
active

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active body is called a menstruum, or solvent: the passive substance which is dissolved, is termed the solvend. Thus when a quantity of salt is put among water, it is dissolved by that fluid. The water, in this case, is a menstruum. The salt is the solvend. In the same manner aqua fortis is a menstruum to silver, which, being dissolved by it, is its solvend.

THE phænomena are easily explained on this theory of solution, which, indeed, has ingenuity and merit. A drop of water placed on a table, soon disappears; why? because from the moment of its being exposed to air, a solution is carrying on, which is not terminated till the water is entirely dissolved by that fluid. Though spontaneous evaporation does not require for its production a great quantity of heat, yet is that production facilitated by heat. In the same manner, solution is performed with much greater celerity, by the assistance of heat. Sugar or salt will melt or dissolve much sooner in hot than in cold water. Nay, in some solutions, when the solvend is entirely dissolved by heat, it
may

may be restored, by allowing the mixture to cool : how ? — the menstruum will drop or precipitate part of the substance which it had formerly dissolved. Is not the same process observed in nature, in the case of nightly dews ? During the influence of the sun in the day-time, vapours arise in great abundance, from the surface of the earth ; or, to use the language of this theory, the watery particles are dissolved by the air, which particles are again dropt or condensed, and put on the form of dew, when the sun has descended below our horizon, and, consequently, ceased to have any influence in promoting a solution of this kind.

SPONTANEOUS vapour is not more promoted by heat, than by agitation. Water confined in a small-mouthed phial evaporates very little, because of its slight communication with the external air. Water in a tub, or suspended in a sponge, is observed to evaporate in great quantities. Where there is little motion of the air, there the evaporation is proportionably little. When the air is free,
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open, and in agitation, the evaporation is not limited in this manner. This is exactly what happens in solution, where, as in a mixture of sugar and water, the sugar is dissolved with much greater facility by being stirred.

IN this manner, to mention no more instances, are the phenomena explained on the theory of solution. But to all this is opposed an insurmountable objection, namely, that this evaporation is produced in greater quantities in vacuo, than in the open air. Were the phenomena of vapours and exhalations truly to be explained on the theory of solution, in which the air is supposed to act as universal menstruum, we should expect that where air is not admitted, no such appearances should take place :—as the solvent cannot be dissolved without the presence of the menstruum. To this it has been answered, that it is impossible to purge the water so entirely of air, but that some part of it must remain ; and that if heat be applied, the air, that was formerly fixt, will resume its elasticity, and so act as a menstruum in dissolving
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the water, and raising it in steam. But this cannot be, because it is always observed that the evaporation is greater, as the air-pump is more and more exhausted.

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SECTION IV.

IGNITION.

BODIES, in certain degrees of heat, appear luminous. A body, which is thus rendered luminous, is said to be ignited; and the effect itself is called ignition.

WHAT the connection is between light and heat we have not yet been able to determine. That there is, however, a connection, is manifest. The stronger the light is, the more intense is the heat: and on the other hand, the weaker the light, the fainter is the heat. The sun is much hotter than the moon. Dr. Boerhaave's reason for this great superiority in point of heat is fanciful. He supposes that the rays of the sun are more parallel to the earth than those of the moon, and that their influence is consequently stronger: but the difference of the parallelism of their rays is, in fact, so trifling, that it could produce very little difference in their intensities.

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The true cause of the difference in heat of the sun and moon, is the superiority of the light of the former above that of the latter.

THE sun is said to be 300,000 times hotter than the moon—Why? because it is incredibly more luminous. How faint the light of the moon is compared to that of the sun, is obvious from daily observation. The moon, being admitted into a room lighted with candles, is scarce observed. A candle, or a number of candles, placed in a room where the sun shines, will not only forbear illuminating the bodies in the neighbourhood, but the flame will almost totally disappear. So vast is the disparity betwixt the light of these luminaries!

THE degree of heat in which bodies begin to be luminous, or emit light, is thought to be fixed, not only to the same body at all times, but to all different bodies. A number of substances being put into a crucible, and a heat applied, which is moderately increased, all begin to shine at the same time;

and, as the heat is increased or abated, to assume a deeper or fainter red. We have indeed no sufficient standard for estimating the same or different degrees of ignition. The only standard is the organ of sight, which is differently affected, as the circumstances differ. A person coming out of a room full of candles into a place moderately lighted, shall think it quite dark. On the other hand, one who is long confined to a dark room, shall find his eyes dazzled on the admission of light.

AMONG the other experiments performed by Sir Isaac Newton, with a lump of red-hot iron, it was the professed intention of some to estimate the different degrees of ignition. To these degrees Sir Isaac assigned different names, from the white-red, when the substance is taken out of the fire, to the pale-red, when it begins to cease to be luminous. At the same time he attempted to discover the degrees of heat necessary to melt certain substances, such as tin, lead, and bismuth; this he effected, by putting them on the iron,
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and observing at what degree of heat in the iron they were melted. Succeeding experiments agree surprizingly with Sir Isaac's calculations.

THAT ignition is an universal effect of heat, may, I think, very fairly be concluded from the variety of bodies in which it is found to take place: for, although many substances have never been rendered luminous, yet would it be unphilosophical to say that such substances are incapable of ignition; because the degree of heat necessary to produce that effect is much more than sufficient to send them off in vapour or steam.

WATER even, which is generally used in extinguishing fire, may, by the assistance of strong mechanical pressure, be rendered so hot, as to melt lead, tin, and other bodies. Now, according to accurate experiments, the degree of heat necessary to melt such substances is little inferior to the lowest degree of ignition. Water, therefore, is capable of ignition, and in Papin's Digester has actually

display'd it: and steam from water, has, in the Æolopile, been rendered ignited, as a variety of experiments made upon it, sufficiently evince.

SECTION V.

INFLAMMABILITY.

ANOTHER effect of heat, though not so universal as either of the former, is inflammation. This is peculiar to a certain class of bodies, hence called inflammable.

OTHER bodies transmit the heat which is communicated to them, without remaining one moment in the same degree of heat. A lump of iron heated and exposed to air, soon diffuses the heat which it possesses to the bodies immediately in its neighbourhood. This heat it is not possible to ascertain amidst the vast mass through which it is diffused: and hence some have imagined that heat, transmitted from one body to another, is annihilated or destroyed, because it is seldom to be found in the same quantity in the bodies to which it is transmitted, as in the transmitting body.

INFLAMMABLE bodies are of this singular nature, that, when once heated, they retain
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the heat which is imparted : and as that is, in part, carried off by the bodies in their neighbourhood, they are supplied from their own proper funds, without requiring the addition of extraneous heat. Such is the case with sulphurs, fossile coals, and bitumens. A very trifling cause too, as a spark from a flint, is able to produce so remarkable an effect.

INFLAMMABLE bodies, when the inflammation is over, are reduced to a substance that is of a quite opposite nature, being entirely uninflamable. Thus fossile coal leaves behind it, after inflammation, a quantity of ashes. There are some inflammable substances, indeed, which seem to contradict this rule, and, in appearance, leave no residue. Such are sulphur and spirit of wine. But upon nicer examination, the latter is found to emit a sort of invisible vapour from the flame, which, by the proper application of watery humidity, can be condensed into an uninflamable watery substance : and if the experiment is properly conducted, there will appear a greater quantity in weight of this last uninflamable substance, than of the original

original spirit : a fact which is astonishing, and absolutely unaccountable. In the same manner, the fumes which arise from sulphur in a state of inflammation, and are so noxious to all animals, can, by proper apparatus, be condensed into an acrid, corrosive salt, which is also greater in weight than the original sulphur.

As inflammable bodies differ so remarkably from other bodies, chemists have supposed a certain principle in all such bodies which regulated their aptitude and disposition to inflammation. This principle they have called by the name of Phlogiston, or the Inflammable Principle; though, perhaps, the Principle of Inflammability would be a properer and more unexceptionable title.

THAT such a principle really exists, they bring many facts to evince: for instance, that an inflammable body, after inflammation is over, that is, when it is reduced to an un-inflammable substance, being mixed with some other body, so as to keep it fixed, and being exposed to a great degree of heat, will,
upon

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upon the mixture of any inflammable substance, be reduced to its original inflammable form. What is surprizing, and bids fair to impress conviction of the existence of such a principle, is, that the same effect will be produced, whatever inflammable substance is added to the mixture, whether animal, vegetable, or mineral. Thus sulphur, after inflammation, and condensation of its fumes, is reduced to a quantity of corrosive salts, perfectly uninflammable. These, united with another body, and joined to some inflammable substance, as charcoal, will be reduced to its original form; that is, a mass of sulphur will be re-produced.

IN short, though it is perhaps impossible to bring certain conviction of the existence of such a principle, yet so many phænomena are easily explicable upon it, that we shall suppose such a principle really to exist in all inflammable bodies.

To produce inflammation in inflammable bodies, it is necessary that heat be first introduced into them. The inflammation will
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not take place without this necessary circumstance; and if cold is applied in considerable quantities, after the inflammation is begun, the effect will cease, and the inflammable matter be no longer dissipated. Thus a quantity of water thrown upon burning fuel, prevents it from being consumed, by putting an end to the inflammation.

Inflammation is a great promoter of fluidity and elastic vapour. Spirit of wine, an inflammable substance, retains its fluidity a long time, without being frozen; and is, on the other hand, easily converted into vapour.

To promote inflammation, the presence of air is absolutely necessary. — Spirit of wine, when inflamed, having an inverted glass put over it, where but a small quantity of air is lodged, the inflammation soon ceases. A candle that burns briskly in the open air will soon be extinguished, if an inverted glass bell is suspended over it. That a change is not produced in the inflammable body, so as to
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put an end to the inflammation, is evident from this circumstance, that the inflammation will proceed in the same substance when the air is restored. That a change produced in the inclosed air affects the inflammation, appears from hence, that a fresh quantity of inflammable matter being exposed to the same air, will instantly cease to be inflamed. What that change is which is thus wrought upon the air, in these circumstances, has long been matter of dispute among the learned. Some have delivered it as their opinion, that air lost its elasticity by inflammation; and some specious experiments have been brought to authorize the opinion: but it is not probable, upon the whole, that air sustains such a loss of its spring as is pretended; nor, were that the case, could it well account for the matter in question. Others have thought they explained this appearance by saying, that the air is loaded with vapours, and therefore unable to support the flame. A third sort more ingenious, have supposed, that air contains a certain matter necessary to inflame, which, in the present case, is spent. This matter,
which

which they term *pabulum ignis*, is supposed to be an acid; as acids are violent promoters of inflammation. But, in confirmation of this theory, no experiments have been offered: on the contrary, there is found no quantity of the nitrous acid in air, which is one of the most violent in promoting inflammation. It is most probable that the air receives something from the inflamed body, which produces such a surprizing change.

AIR, thus changed by inflammable substances, is found to be very unfit for the purposes of respiration. Affected in this manner by burning charcoal, it deprives animals of sensation, and even of life: and what is still more surprizing, an air, frequently breathed, and thence rendered unfit for respiration, is likewise totally unfit for inflammation. Hence the nature of this air has been matter of dispute to physicians as well as natural philosophers.

FROM the observation of the effect of air in promoting inflammation, may be drawn
many

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many useful conclusions. As fuel cannot burn without air, we can always regulate the degree of inflammation, by increasing or diminishing the quantity of air which is admitted to enter it.

END OF THE FIRST PART.

P A R T II.

GENERAL OBSERVATIONS

ON THE

Theories of MIXTURE.

THOUGH several bodies are not disposed to unite by mixture, as oil and water, quicksilver and water; yet many substances are capable of being so intimately united, that the mixture, after union, appears perfectly homogeneous.

THE effects in cases of mixture are greatly diversified. Sometimes they are produced slowly, and without any seeming rapidity or violence; thus sugar is mixed with water

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slowly

slowly into a syrup; salt incorporates itself with the same liquor, and with similar calmness. At other times, the mixture is not effected without considerable violence, motion, and production of heat.

EXPERIMENT I.

EQUAL quantities of the vitriolic acid or oil of vitriol and pure water, of the same temperature, being put into a Florentine flask, produce a great heat on being mixed together, and, upon agitation, emit a quantity of steam. The heat generated in the mixture is sensibly felt by applying the hand to the bottom of the flask, which, in fact, is so extremely heated, that water sprinkled upon it is sent forth in steam.

EXPERIMENT II.

SPIRIT of sal ammoniac, and the vitriolic acid mixed together, produce violent commotions, and occasion a variety of white fumes to arise.

THERE are cases still more violent than these; in which not only a greater quantity
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of fumes arises, but these fumes break out into flames. This turbulent motion is called Effervescence; and bodies thus agitated, are said to effervesce together.

THE instances hitherto adduced relate to the mixture of fluids with fluids only. Solid substances, however, are frequently torn asunder with the same impetuosity as that mentioned in the last experiment, and become as intimately incorporated with the fluid to which they are joined as any two substances can be possibly conceived to be. The mixture appears pure and perfectly homogeneous, and would, if no change is made upon it, continue to conceal the solid in it for ever.

As in the mixture of fluids with fluids the effects in point of rapidity and violence are greatly diversified; so in the union of solids with fluids, the degree of violence is in no two instances exactly the same.

EXPERIMENT III.

SOME bits of camphire being thrown into a glass containing a small quantity of spirit

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of wine, disappear, in a short time, in the liquor, in a quite equable manner, and without any rapidity whatever. The spirit of wine, after the camphire is mixed with it, suffers no diminution of its transparency; no diversity of constituent parts being to be observed by the sight. To effectuate the mixture in a shorter time, the liquor may be agitated. Agitation, however, is not absolutely necessary; the camphire would dissolve of itself in time.

EXPERIMENT IV.

INTO a quantity of spirit of salt is put a hard piece of stone or marble; a foam or froth is immediately excited, as if the marble had been put into it red-hot: and the substance at length disappears in the liquor, without any diversity of parts being to be observed in the mixture. The effervescence continues till it is dissolved.

IN most cases of mixture, we find it much more difficult to separate the ingredients, or decompose the substance, than, from a knowledge of their nature, we might reasonably

sonably expect. In treating of vapour we observed that different degrees of volatility point out a method of separating compound bodies. But bodies incorporated in the manner just mentioned are with difficulty separated by volatility. A volatile mixed with a fixed body is not so easily volatilized, as when in its separate state; and even when, by the force of heat, it is made to rise in vapour, that vapour is not solely of the volatile body, but of the mixture. In the first experiment, where water and the vitriolic acid were mixed together, though the former, in its separate state, is volatile at 212 degrees of heat, the boiling point; yet a heat of that degree of intensity will not volatilize the water combined in this manner; nay, perhaps, an addition of 100 degrees will scarce be sufficient for producing that effect; and the vapour which arises is not of the water but of the mixture. In fine, the water would not be entirely volatilized; some part of it would still remain fixed with the acid, from which no force of heat could possibly disunite it.

IN the second experiment, where the spirit of sal ammoniac, a volatile body, is united with the same fixed body, viz. the vitriolic acid, the sal ammoniac, in consequence of that junction, loses its volatility, as is evident from its losing the pungency of its smell.

IN the fourth experiment, marble is dissolved in spirit of salt. This last substance is nearly of the same volatility with water; and if the spirit is strong, it is more volatile; yet, when it has acted upon the marble, it can bear a great degree of heat without being converted into vapour.

DIFFICULT as it is, by means of volatility, to decompose substances that are united by mixture, yet a third body added to this mixture, unites itself to one of the two, in preference to the other, and thus produces a separation in the compounded substances.

To the mixture of spirit of sal ammoniac, and the vitriolic acid, which was found to be void of smell, if the caustic fixed alkali be added,

added, it will join itself with the vitriolic acid, and restore the smell of the sal ammoniac, though the alkali itself has no smell. Water added to the mixture of camphire and spirit of wine, will restore the camphire in a curdy substance. Marble dissolved, as in the fourth experiment, is restored by throwing in some of the caustic alkali, which joins itself to the acid. In consequence of that junction, a white substance is formed, which falls to the bottom, and, upon examination, is found to be the collected atoms of the marble.

AQUA FORTIS dissolves silver; quicksilver restores it, and is itself dissolved; copper being dissolved, restores the quicksilver, and is itself restored by the addition of lead; the lead is restored by another metal; and this by the caustic fixed alkali. Thus a manifest gradation is going on, and substances compounded so intimately by mixture, as to form one seemingly homogeneous substance can be perfectly separated by the addition of a third body.

To explain these facts, and others of a similar nature, various theories have been framed, the greatest part of which have been more fanciful and ingenious than true. Indeed, till the time of Lord Verulam, no intelligible theory had been formed upon this subject. The chemists of the ages previous to that great philosopher, were little acquainted with the principles of reasoning: confined entirely to the study and improvement of their own science, they never thought of attempting to explain its phænomena, by comparing them to similar phænomena in common life,—a method which has seldom failed to end in the investigation of truth. We have a remarkable instance of the efficacy of this sort of analogy, in Sir Isaac Newton's theory of the heavenly bodies being contained in their orbits by gravitation—the same power by which a stone falls to the ground. The chemists, familiar with nothing but chemistry, explained its appearances from its own funds, and were even disposed to account for common facts on chemical principles. Besides the mistaken reasonings of these first professors, the nature
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of the science itself is unfavourable for theory. The phænomena are extraordinary, uncommon, and unlike most other things. Hence little certainty would obtain in attempting their explanation. Upon mechanical principles a rock may be moved by one man ; — the fact is astonishing, when we do not attend to the mechanical powers by which this effect is produced : but when we examine the instrument, its apparatus, and inform ourselves of the vast extent of mechanical power, our wonder ceases—and we find that force is increased at the expence of velocity. But when a rock is moved by a chemist, by the action of salt petre, sulphur and charcoal put under it, we find it very difficult to explain how such an amazing effect is produced — no mechanical force that we know is lodged in or exerted by these materials. It is like nothing in nature. Of the same kind are all chemical facts. Lord Verulam, and afterwards Mr. Boyle, in several ingenious dissertations, attempted to establish a theory for appearances in chemistry upon mechanical principles. They supposed that the particles of bodies were differently formed

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ed as to figure, and differently agitated, some in a greater, others in a less degree. From this theory they accounted for all the curious facts with which chemistry abounds. Succeeding chemists, particularly among the French, have pushed this theory to a degree of extravagance and absurdity, and involved themselves in numberless errors and inconsistencies. They, for instance, pretend to explain the heat produced by the mixture of the vitriolic acid, and water in the first experiment, by saying, that the acid is a saline, heavy, inert substance, containing particles of fire, which, from its heaviness, are restrained from breaking out — but that the water mixing with and diluting it, takes off that restraint, and produces the heat.

THE dissolution of the marble in the fourth experiment is accounted for, by saying, that the spirit of salt consists of particles of the form of needles and wedges, in constant motion through the liquor, which insinuating themselves into the marble, a porous substance, soon tear it asunder. But it is evident that here are many things supposed, for
which

which there is no foundation. How do we know that the vitriolic acid contains particles of fire? What reason for believing that the particles of the spirit of salt are like needles and wedges, and in continual agitation? It is indeed pretended, that the motion of atoms in the air, which are rendered visible by sunshine, afford a very convincing argument of the continual motion of the particles of the liquor—but the motion of atoms in the air can be accounted for, being excited chiefly from the breathing of animals, and is often rendered visible. Such a motion of a watery liquor cannot be accounted for, and is never rendered visible. But supposing such a motion to exist, its effect would not be to produce the solution—for solid bodies, whose particles, it is not pretended are in constant motion, have the same effect. Earths, which, in their separate state, cannot be rendered fluid, are melted when mixed with others, with no very violent degree of heat. Regulus of antimony, and mercury sublimate, act upon each other in the same manner. The higher phænomena are with still greater difficulty explained upon these principles. Aqua
regia

regia dissolves gold, but not silver. Aqua fortis dissolves silver but not gold. The pores of gold, said the theorists, are small, and resist the action of the sharp particles of the aqua fortis: but are the pores of silver, which is easily torn asunder by aqua fortis, so small as to resist the action of aqua regia?

MR. Langelot delivers it as his opinion, that the union of a solid and fluid depends upon the minute division of the particles of the solid. In confirmation of this theory, he relates an experiment of gold dissolved in pure water, merely by trituration: a piece of gold-leaf rubbed betwixt the hands and put with water into a mortar, and there still farther beat, passes into a philter, where no diversity of constituent parts is observable. But it is certain, that the particles of the gold would subside by their own weight, in time, though the smaller the particles, the longer time they will take to subside. Upon the whole, this theory of minute division accounts for the suspension of the gold only, not for the solution. To explain the phenomenon of the pieces of marble separated by a third substance, the
theorists

theorists pretend, that the fixed alcali breaks in pieces the pointed particles of the aqua fortis, and so disengages it from the marble; but they do not foresee, that in this case, the aqua fortis could not be restored, seeing its points are blunted, in which points, say they, consists its power. Yet the aqua fortis can be recovered entire both in quantity and efficacy. These theories are plausible, but insufficient. The last and most generally received theory, is that of Sir Isaac Newton, who has extended the doctrine of gravitation to explain chemical appearances. In his system of the universe, he accounts for the heavenly bodies being retained in their orbits, upon the same principles by which a stone falls to the ground. To this power he gave the name of attraction. He afterwards observed, that there were other forces in nature of the same kind, as the action of the magnet; the effects of electricity, some times attracting, sometimes repelling; of transparent mediums on the rays of light; and the attraction of liquors in capillary tubes. In his further researches, he discovered, that the small particles of bodies act strongly upon each

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each other. This power he called cohesion. Two pieces of marble finely polished, applied to each other, are with difficulty pulled asunder: this obtains both in air and in *vacuo*. The same thing happens in the softer metals. Two pieces of lead having their surfaces cut clean, and twisted with some force, will adhere as strongly as if united together. From the consonancy of nature in all her operations, Sir Isaac suspected that chemical facts depended upon some such attracting power. He has delivered his suspicions upon this head very modestly, and at great length, in the end of his Treatise on Optics. The substance of what that great philosopher advances is as follows: that when two fluids mix with rapidity, motion, the production of heat, and sometimes of flame, these effects are in consequence of a certain specific attraction betwixt the particles of the two fluids. As this attraction is greater or less in different fluids, the appearances are different; the substances rush through each other with greater or less impetuosity; and when the friction or collision is very great, we need not wonder that heat and even flame should be produced, as these

these are commonly the consequences of violent collision. Again, when a solid body is torn asunder in a violent manner by a fluid, the attraction betwixt the particles of the fluid and solid is stronger than that of the particles of the solid, by which its solidity is preserved. When a volatile body, united with a fixed, loses its volatility, as sal ammoniac in the second experiment, united with the vitriolic acid, loses its smell; this effect is produced by a very intimate attraction between the volatile and fixed bodies, as is evident, if we consider, that volatility is a repellency among the particles of any body, by which they are disposed to fly off in vapour. Now, when a fixed body is united with the volatile, this repellency is prevented or destroyed: How? Certainly by something opposite in its nature to repellency, that is, an attraction betwixt the particles of these two bodies. Thus the diminution of volatility in chemical facts of this kind, is a strong argument for the theory of attraction. Lastly, when a separation is effected betwixt two bodies that have been combined by mixture, by the application or addition of a third, is it not manifest that
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the attraction betwixt that third body and one of the united bodies is stronger than that which operates in preserving the union of the bodies so combined?

SUCH are the great out-lines of the theory of attraction, which is certainly ingenious, easy and simple, and was received by the learned, from its first appearance, with the highest pleasure and approbation. It is accordingly the only theory which is almost universally received at this day. Objections, indeed, have been started by the French and German chemists. The former wedded to Descartes, and the mechanical philosophy, were little inclined to give into a theory which clashed so strongly with their favourite opinions. They objected to Sir Isaac, that he considered attraction as some connecting material substance, notwithstanding his repeated assertions, that he did not mean by attraction the cause, but the forces themselves. The French philosophers have proposed the term affinity, in place of attraction; and accordingly, that term is to be found in most of their writings. It is, however, highly improper, as seeming to

to intimate a similitude betwixt the bodies so united, which does not, in fact, exist. What resemblance is there betwixt silver and aquafortis ; marble and the same liquor ; and so of others ?

THE German chemists opposed the theory of attraction on different principles, but with similar spirit. Enemies to theory, and assiduous only in accumulating facts and experiments, they were disgusted at the extravagant lengths to which this theory has been pushed by some of our own countrymen, particularly by Dr. Friend in his Chemical Lectures.

CHEMICAL attractions differ from those of gravitation, magnetism, and electricity, in that they do not act between large masses of matter, but betwixt the very small particles of bodies ; I say, the very small particles, for the minuteness of the parts of bodies is so exquisite, that it goes beyond imagination to conceive,

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EXPERIMENT

EXPERIMENT V.

A MINUTE grain of salt of silver put into a large bottle of distilled water, is diffused through every drop of the liquid. To be convinced of this, we need only put into the mixture a small quantity of spirit of salt, which has an electric attraction to the salt of silver; and a fine whitish small dust is immediately formed, which disturbs the transparency of the liquor. A little of the same spirit put into the water in its pure state, has no such effect. That the silver is diffused through the whole liquor is manifest from this, that each drop, examined by the microscope, is found to contain a small minute portion of the silver. Nay farther, the salt of silver consisted of the same number of minute particles, before immersion, actually divided; for the aqua fortis divided the silver into the minute parts just mentioned; silver itself put into water would not be divided in the same manner.

As chemical attractions act only between the very minute particles of bodies, their influence

fluence reaches to a very small distance, and is quite imperceptible by our senses. Thus, to incorporate brimstone and quicksilver, it is not sufficient to reduce the first mentioned substance to the form of dust, and to pour the quicksilver upon it; they must be grinded together with great pains, and for a long time, till they are reduced to a powder of a black colour.

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RULES, OR CANONS,

For effecting CHEMICAL OPERATIONS.

I. TO make two bodies act upon each other, it is necessary that one or both should be fluid, or be disposed to fluidity. Two fluids act upon each other almost instantaneously.

EXPERIMENT VI.

SAL ammoniac, which contains volatile salts, has its volatility suppressed, when united with a saline substance. Salt of tartar, which has an elective attraction for the saline substance, being mixed with the compound, both dry, no effect is produced, nor probably ever would be produced, if the substances are kept free from moisture. The smell of the sal ammoniac would be restored, if a separation took place; but there is no such separation. The grains of the salt are quite distinguishable from each other; no composition or intimate union takes place: How then is the separation to be effected? By pouring a little water upon
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the salts, which soon renders them liquid, disposes them to act upon one another, and by restoring the smell of the sal ammoniac, demonstrates that it has produced the separation required.

EXPERIMENT VII.

SALT of tartar and salt of amber, mixed while dry, produce no effect; a little water disposes them in like manner to act, and excites a strong effervescence. It may be asked, How fluidity disposes bodies to act in this manner? The answer to such a question is by no means obvious. Perhaps, fluidity brings the small atoms of such bodies into closer contact, and thus disposes them to unite with, and pervade each other.

CANON II. When we desire to hasten the solution of a solid in a fluid, the solid must be divided mechanically, in order to have its surface enlarged; in other words, the substance must be reduced to powder; or if ductile, as most of the metals, be beat out into thin plates, for the purpose of being more easily pervaded by the fluid, which acts upon

the surface, as it is there in close and intimate contact. Gold melted and poured into cold water, forms itself into a number of small globules, which are more easily dissolved than the same substance would, if immersed into the fluid in a larger form.

CANON III. To promote solution, moderate heat is necessary. Though it cannot be explained, heat not only disposes bodies to mix more readily, but in greater quantities, increasing both the celerity and power of the solvent. Thus, water when heated dissolves a greater quantity of salt than when cold; the excess precipitating itself, when that fluid is allowed to cool. Farther, a certain diminution of heat will destroy the efficacy of some chemical attractions altogether. Thus water at 32 degrees below 0 will not dissolve salt; and if the salt has been previously dissolved in the water, it will, in such circumstances, separate. Hence the use of digestion, circulation, and cohobation, chemical processes which depend on the efficacy of heat in promoting mixture and the combination of bodies.

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WHEN a solid is dissolved in a fluid in a vessel, by the assistance of a gentle heat, the process is called digestion. When the heat is so strong, or the time of digestion so long, that vapour arises from the substances, which is by proper apparatus, condensed and restored to the evaporated mixture, the process is called circulation. And lastly, when the vapour is not condensed into the same vessel, but received into a lateral vessel, and by the operator poured back into the vessel from whence it arose, the process is termed by a barbarous word, cohobation. These processes are of great utility. Saline liquors, which do not operate on the metals in ordinary circumstances, will operate on them by means of a gentle heat continued for a long time.

THE most curious of all the chemical attractions is that which is observed in the separation of a compounded body by the addition of a third. The cases of this sort are numerous and greatly diversified. The body which is added in order to decompose the other, may have an attraction for both the ingredi-

ents of which the compounded body is composed ; yet will it join itself with that ingredient for which it has the strongest attraction. This can be rendered evident by uniting the same substance to a body which it attracts but weakly, and then throwing in another body for which it has a stronger attraction. The weaker will immediately be separated, and the substance last thrown in be united with that for which its attraction is comparatively stronger. Attractions of this kind, from the choice that appears in their operation, are stiled Elective. That these appearances depend upon a superior attraction is farther manifest from this, that the last step in the gradation or election is always found more difficult to decompose by heat. Separation by heat or volatility is accomplished with less or greater facility, as a greater or less attraction takes place.

Mr. Geoffroy, sen. has reduced instances of this kind of elective attractions into the form of a table. Thus, in order to express the comparative attraction of aqua fortis to the several metals, he has constructed a column,

at

at the top of which is placed aqua fortis—then the several metals according to their superior degree of attraction. 1. Zinck. 2. Iron. 3. Lead. 4. Copper. 5. Quicksilver. 6. Silver—that is, silver has a less attraction for aqua fortis than any of the metals mentioned before it; quicksilver has a stronger attraction than silver, but less than any of the others. Silver then may be separated either by quicksilver, copper, lead, iron or zinck. Quicksilver may be separated by copper, lead, iron, or zinck. Copper by lead, iron or zinck—and so of the rest.

THIS method, however ingenious, has been objected to by chemists as false and erroneous. The errors that are chiefly insisted on, arising from an improper arrangement of several of the articles, are not very material: though perhaps every such calculation must suffer from this circumstance, that the force with which a particular body acts upon another is not always precisely the same.

A COMPOUND of two ingredients added to another compound produces two compounds
totally

totally different from what they were before. Such attractions are called Double Elective Attractions, and by the French, Double Affinities; they are of great utility, as we may often obtain, by their means, and with no additional trouble, two powders instead of one.

THERE remains but one remark upon this subject, which, though curious, has been but little attended to. It is this; when two bodies are united, their bulk, in this combined state, is different from the sum of their bulks, when separate; being sometimes less, often greater — scarce an instance occurs, where the bulk before and after combination is exactly the same. Mr. Lewis, in his curious experiments on the mixture of platina with other metals, paid particular attention to this circumstance; as did likewise M. de Reaumur of the French academy, with whose accurate and decisive experiment on this subject I conclude this part of the essay. Having taken a vessel of the shape of a thermometer, and filled it half full of water, he poured slowly upon it a little spirit of wine, which being
lighter

lighter than the other fluid, floated upon its surface. He then inverted the vessel, with a view to produce a mixture, and allowed it to settle till the gentle degree of heat, occasioned by the union, should be dissipated. After settling, he found, by means of a mark which he had made in the neck of the vessel, that the liquor stood much lower than before the spirit began to incorporate itself intimately with the water.

APPENDIX.

A P P E N D I X

ON THE

Form and Use of the VESSELS

That are employed in conducting

CHEMICAL OPERATIONS.

IF such vessels as we could wish, were possible to be obtained, we would desire them to be possessed of the following properties. 1. To be transparent, so as we could see clearly what effects are produced on the subjects. 2. To be unaffected by any solvent that is put into them, which by its activity, might corrode them. 3. To bear sudden alterations and vicissitudes of heat. 4. To be strong, so as to be in no danger of cracking, and breaking. 5. To endure a violent heat, without melting.

As vessels possessing all these properties are not to be found, we are obliged to employ

ploy such as have the greatest number, or the most essential of them. Such are glass, metal, and earthen-ware. Glass possesses the two first properties in a considerable degree. The fourth and fifth it fails in, but most in the third. Sudden alterations of heat never fail to break the glass exposed to them. As glass possesses a little flexibility, especially when thin, it is always found more convenient to employ thin glasses for the purpose of chemistry, as the heat applied to a part of the surface naturally expands it, and disposes the parts contiguous to expand in like manner, which, when flexible, they will do, with little difficulty. Thick glasses are not flexible, and therefore are more apt to break than thin ones. The glasses, however, though thin, ought to be made as strong as possible. Glass, if cooled hastily, is apt to break. Bubbles of this substance thrown into water split in a thousand pieces. Drinking glasses are apt to be broken from trivial circumstances arising from the same cause.

METALLIC vessels have no properties in common with glass, but bear sudden alterations

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rations of heat, and may be made to endure a very violent degree of it. The most common metals employed in this way are iron and copper. In moderate heats, lead and tin; where a great heat is required, gold.

EARTHS may be said to have none of the five above mentioned properties but the last, namely, a disposition to endure violent heats without melting. Some earths, indeed, there are, that are not corroded by an active substance; but this is not a general property. The basis, in general, of earthen vessels, is clay, which has the properties of ductility when moist; solidity and firmness when burned. Clays are either pure, as that of which pipes are made, or impure; these last melt and vitrify. Clay used alone gives close dense vessels, but when suddenly heated, such vessels are apt to crack and break; to prevent this effect, the clay must be mixed with a substance which does not expand when heated. Such a substance is sand—accordingly sand is employed in this way. The greater quantity of sand that is added to the clay, the matter becomes less apt to crack: but what is thus gained in
point

point of strength, is lost in point of solidity and closeness. Where the most perfect closeness is required, the best material is porcelain, which is a composition of clay and some other substances united in the most intimate manner. Burnt and pounded clay, added to fresh clay, has been found to answer the purpose very well. Black-lead often goes to the composition of earthen vessels, where the action of the fire to be resisted, is strong.

THE form of all these kinds of vessels is different, according to the uses for which they are intended. We observed above, that to dispose bodies to act upon one another, they must be fluid, or rendered so, and that either by fusion, evaporation, or solution. For each of these operations, certain vessels are appropriated. Those for fusion, are termed crucibles. Because exposed to violent heats, they must be of earth. Their form is conical, wide at the mouth, and narrow at the bottom; because mixtures which are separated by the addition of a third substance, require that the separated substance should form one entire mass at the bottom, to which
the

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the conical figure of the vessel determines it. This sort of separation of metallic substances is called Precipitation, and, to distinguish it from other kinds of precipitation, Precipitation by Fusion. Crucibles are pinched at top into three corners for the conveniency of pouring the matter, when fluid, into another vessel, which is generally of brass and iron, and more conical in its figure. Crucibles have no covers, a circumstance which proves frequently inconvenient. When it is necessary to exclude the air, chemists are forced to invert another crucible into that which contains the subjects, or to lute them with sand and clay.

THERE are two kinds of crucibles with respect to materials, the one of clay and loose sand mixed, called the Hessian Crucible; the other of black lead, and a small proportion of clay, called the Austrian Crucible. Where a violent heat is required, the outside of the first kind of crucible may be pasted with sand and clay, or it may be put within a larger crucible, and the interstices closed up with these materials. For less violent degrees

degrees of heat, other vessels may be used : as for melting lead, an iron vessel ; for melting some saline substances, a glass vessel ; and so of others.

WHEN in volatilizing bodies, the vapour is allowed to escape as useless, the process is called Evaporation, as was formerly observed. If the subjects are water, and some body that has no corrosive quality to metals, a pan, or some open metallic vessel of that kind may be used. If one of the subjects is corrosive to metals, glass and porcelain are proper. A globular figure converging to a narrow mouth is the aptest, as a retort. In evaporating metallic substances, as quicksilver and regulus of antimony, crucibles are used.

DISTILLATION, where the vapour is preserved, is performed three different ways. These are termed *Distillatio per descensum* ; *Distillatio per ascensum* ; and *Distillatio per latus*. In the first, heat is applied above the subject, and the vapour condensed below. In this manner is oil produced from cloves. The cloves placed over a vessel, as a stone
I decanter,

decanter, have a plate of metal placed over them, to which the heat is applied; the fumes being condensed downwards, by means of the cold air, or water in the vessel. The manufacture of tar is conducted in the like manner. This method, however, is not in general use.

IN the second, *Distillatio per ascensum*, the vapour is allowed to follow its natural course upwards for some time, and is then directed aside, where, by means of proper apparatus, it is condensed. Various vessels have been contrived for this purpose. The common copper-still, too well known to require a particular description, is most generally in use. The serpentine pipe for directing the vapour aside is immersed into a vessel of cold water, which condenses the vapour, as it passes through the pipe. In rectifying spirit of wine, or freeing it from water, the spirit, from its superior volatility, rises first. To prevent this from being condensed with the spirit, a tall serpentine head has been proposed to be added to the still, through which the vapour passing before it entered the pipe, might,

might, in its passage, be decomposed; the denser part falling down into the vessel, and the spirit only being volatilized. This intended improvement, however, has not been found to answer. The common copper-still is sufficiently proper in all cases where no corrosive substance is put into it. Where the substances are acrid, glass vessels must be employed. Such are the vessels called Cucurbits; which, when compleat, have capitals or alembics. A pipe issues from the vessel, for condensing the vapour which is received into a phial applied to the pipe. The head is generally adapted by receiving the top of the cucurbit. It has, however, been found more convenient to construct these vessels so that the cucurbit shall receive the top of the head; because, in the former construction, some of the steams settling at top, fall down in little drops, and wash away the luting. In the latter method, the condensed matter falls down into the vessel containing the subjects. The cucurbits require to be higher where the substances are more volatile; where less volatile, they may be lower.

THE most convenient method, however, of distillation, is that which we termed, *per latus*; and this is performed in a glass vessel called a retort and receiver. Here the vapour is not allowed to ascend at all, but immediately directed aside. The vessel is very simple, consisting only of one juncture, that, to wit, of the retort and the receiver; the cucurbit, on the other hand, has three joints. The retort, as well as the cucurbit, may be constructed of different heights for different purposes. For particular operations, especially where a violent ebullition is excited in the mixture, chemists have their retorts open at top, with a piece of glass fitted to the opening, which they can remove occasionally. But there are very few cases, where such a convenience is wanted. Sometimes, in violent ebullitions, we are obliged to pour in but little at a time, lest the violence of the mixture should endanger the vessel.

WHEN retorts are open at top, they are called Tubulated Retorts. Receivers are generally spherical, converging into a narrow cylindrical mouth. This figure is not so convenient

convenient as the conical. Receivers have been contrived with an opening at the upper side to suffer some elastic fumes to escape. These are called Tubulated Receivers, and are exceedingly troublesome to manage; large-sized receivers answer the purpose equally well.

RECEIVERS are sometimes furnished with a pipe at the under part, for separating the different products of the distillation. Such are called Spout Receivers. The same thing may be effected by taking off the receiver, and applying another. The receiver is sometimes bored towards the back part, about one-tenth of an inch diameter, which is opened occasionally, when the steams are too strong to be confined. To give scope for the condensation of very volatile fumes, we make use of what are called Adopters, which are receivers joined to other receivers. The Muriatick Aether is prepared in this way.

RETORTS serve for different distillations, in an ordinary heat only: beyond that at which bodies grow red, glass begins to melt,
and

and is therefore insufficient for being employed in vessels. If the glass, indeed, is coated with clay and sand, the vessels may be rendered stronger, and able to undergo a violent heat. A Florentine flask, thus coated, will endure a very great degree of heat: for, tho' in this case, the glass becomes soft by a red heat, yet its form is preserved by the coating. But if the degree of heat is very intense, we must use retorts of earthen ware; and, in some cases, iron retorts are proper.

IN sublimation, where the product is a solid, the cucurbit is often used, with a blind head, that is, without a pipe issuing from the head, which is not necessary, as no fluid is to be condensed. A retort, however, is more commonly employed with a short and wide neck. I say wide neck, because in narrow-necked retorts the solid matter would be collected in a mass, without passing into the receiver; hence the neck would be clogged, and often liable to be burst. The conical receiver here too is to be preferred to the spherical. In many cases, the matter sublimed is remarkably fixed, and therefore does
not

not rise high. For these purposes, oblong vessels, as Florentine flasks, are proper, and even common phials. Allodials are in sublimation, what adopters are in distillation.

F I N I S.